# Low-Power Retentive True Single-Phase-Clocked Flip-Flop With Redundant-Precharge-Free Operation

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# Agenda

- Introduction
- State of art designs
- Proposed design
- Results and Simulations

# Introduction

- Objective of Paper - To design power efficient flip-flop that can operate at low voltages
- Applications - Sequential circuits which use more no.of flip- flops
- Approach -
  - Voltage scaling
  - Eliminating redundant charging and discharging of internal nodes
  - Optimisation in circuit level

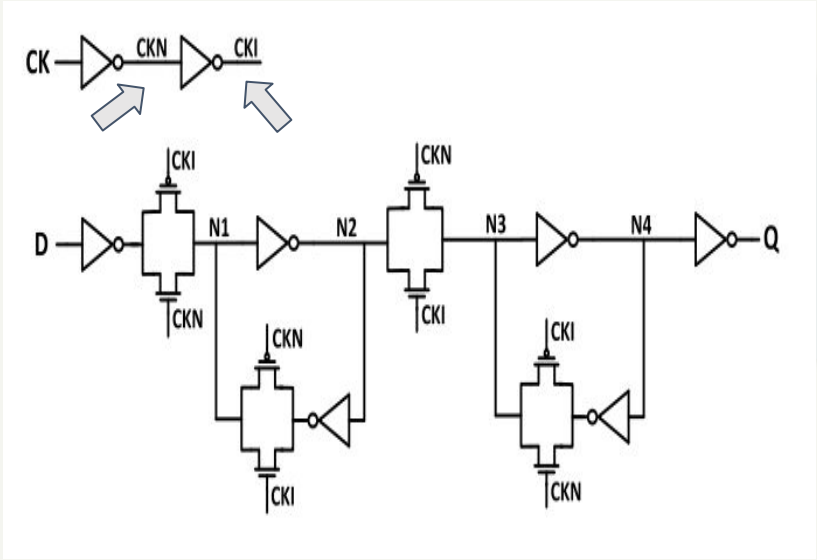
# TGFF

**Advantages**

- No contention on the output node

**Drawbacks**

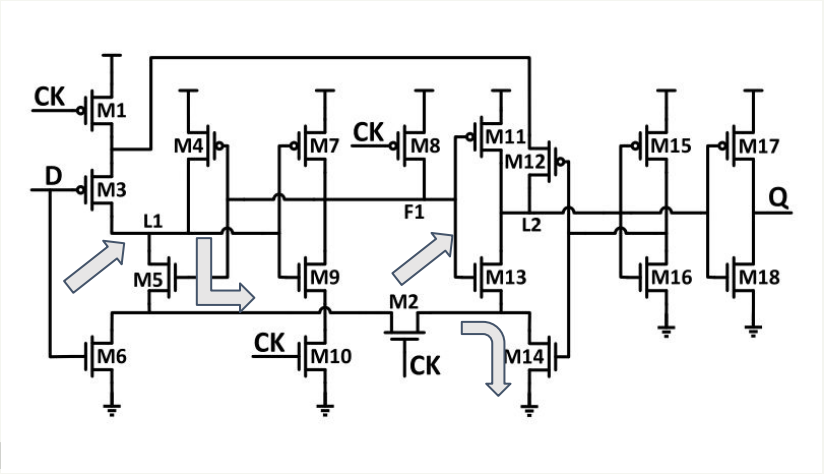
- Large clock network
- Unnecessary toggling of CKN and CKI nodes even when the data activity is 0
- Not single phases clock.



# SPC-18T - Single phase clock Flip-Flop

**Advantages**

- Simplified logic
- No.of transistors connected to clk signal are less




**Drawbacks**

- Redundant charging and discharging of node F1.
- Short circuit path
  D 1->0 L1 charged at neg edge of clk and discharged as shown
- Increase in hold time

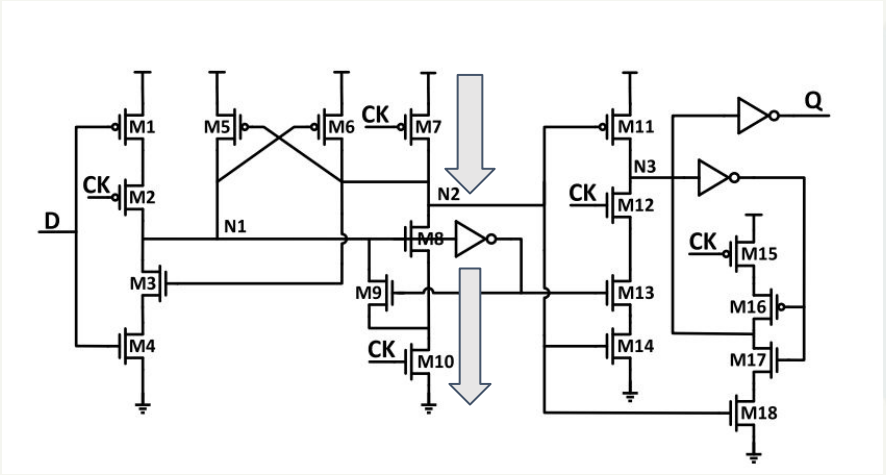
# S2CFF - Static Single-phase-clocked contention-free Flip-Flop

**Advantages**

- No current congestion at output node

**Drawbacks**

- Unnecessary precharge and discharge - When D=0 and neg half cycle of clk N2 is charged by M7 and discharged by M8 and M10 at rising edge

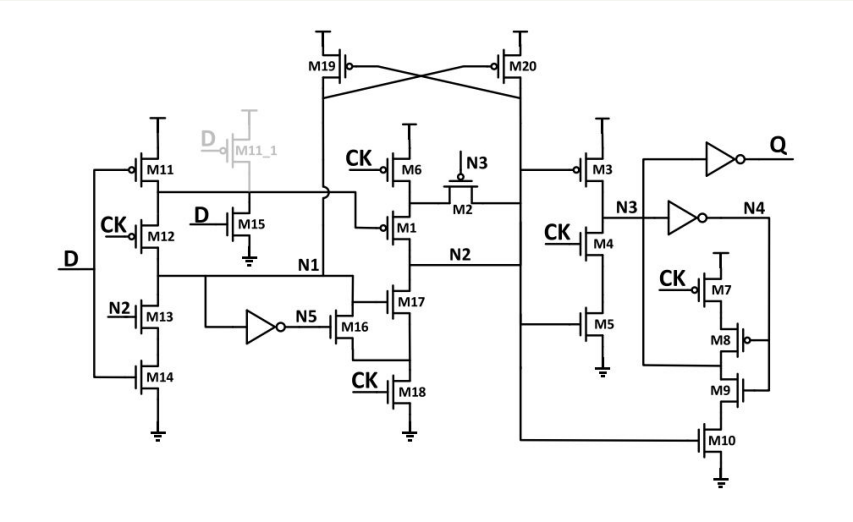


# TSPC - True Single phase clocked FF

**Proposed design**

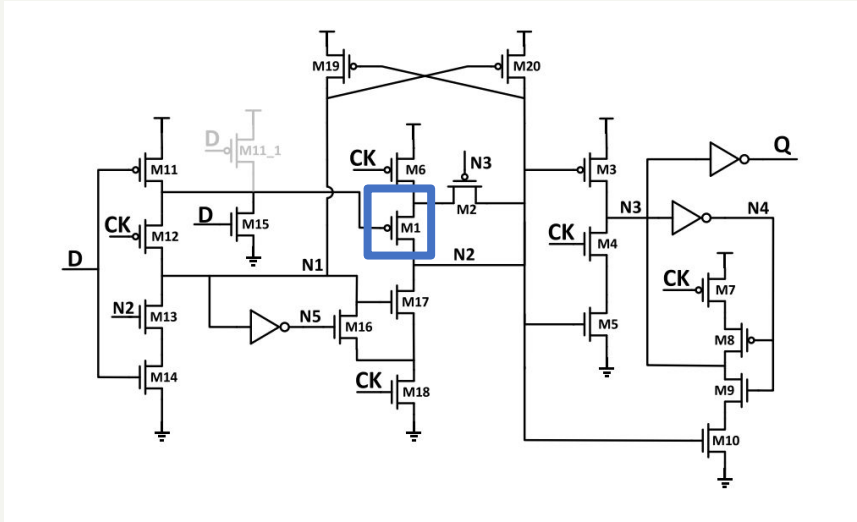
Features

- Input aware pre-charge scheme
- Floating Node Analysis
- Transistor Level Optimization
- Works at sub threshold voltages.



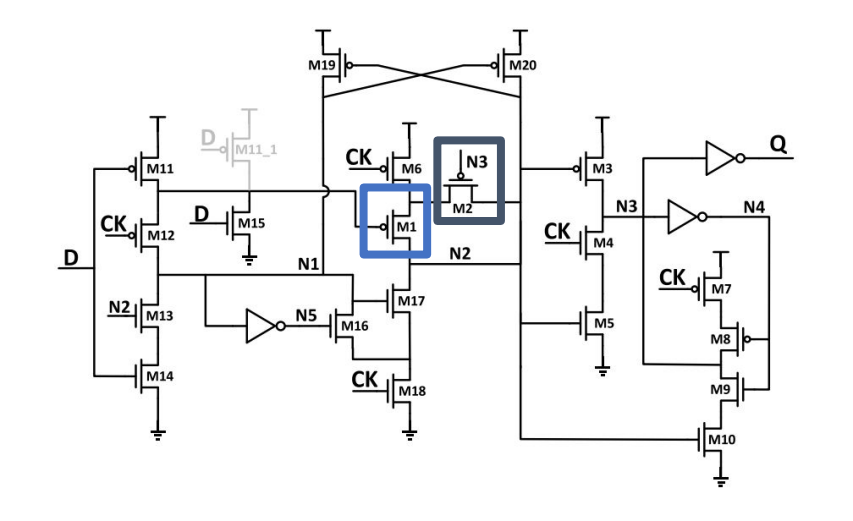
# Input aware pre-charge scheme

- The precharge operation of the node N2 in S2CFF when the input data remains 0 is unnecessary.
- M1 transistor is introduced to eliminate this energy wastage.
- The input of M1 is inverted D so, if D=0 no charging and if D=1 it pre-charges as usual.



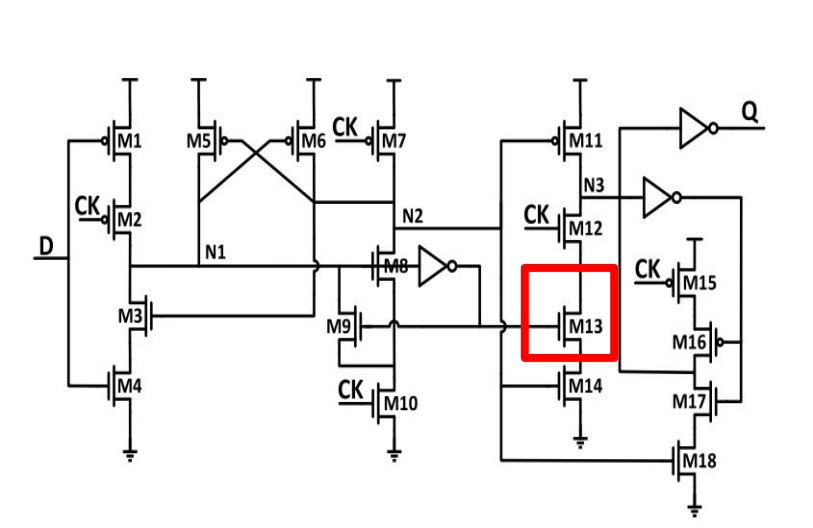
# Floating Node Analysis

- Voltage of floating nodes may change after transition due to the leakage current
- Using eliminated redundant charging of N2 but at Neg half cycle N2 is floating when D=0.
- When Q=1 M3 should be off and M10 on to keep N3 0 so, N2 should be high
- M2 is added to keep N2 high which is controlled by N3.

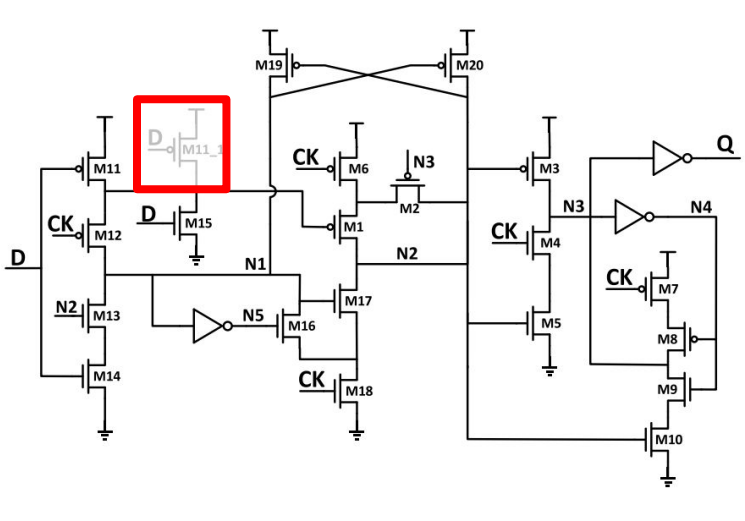


# Transistor Level Optimization

S2CFF

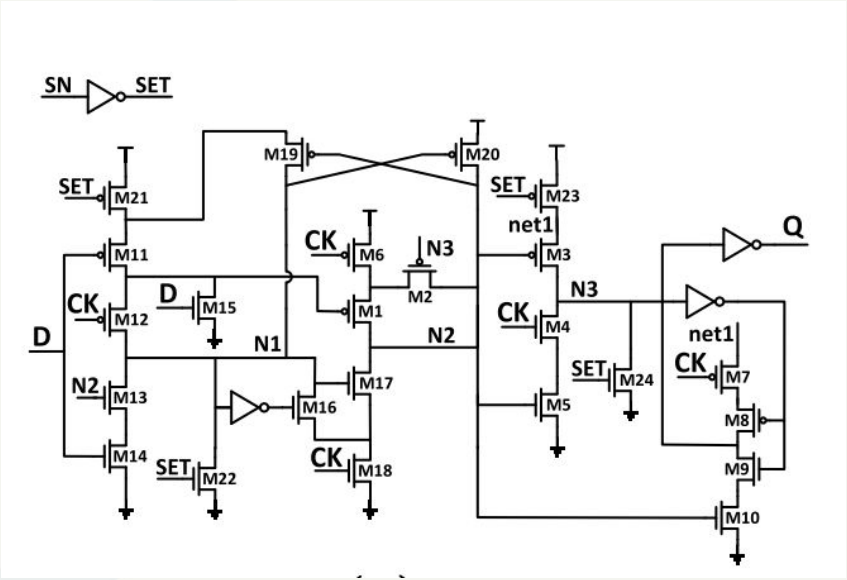



Proposed

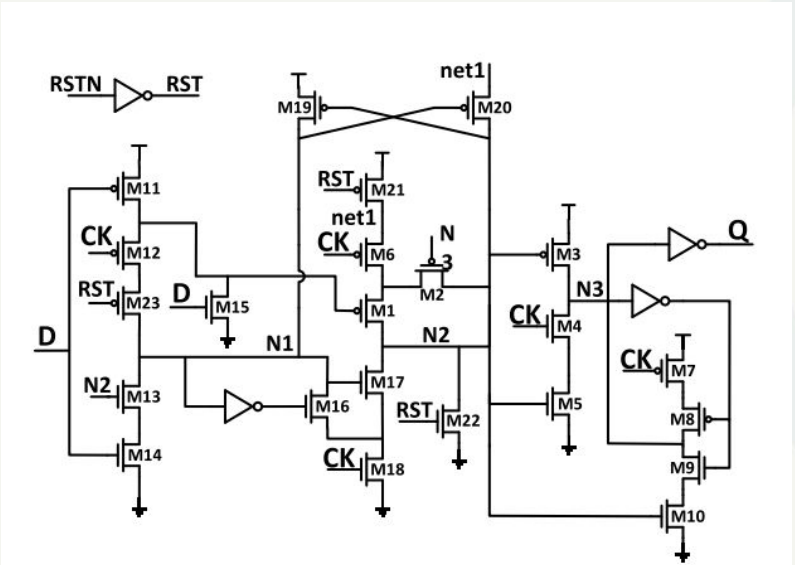


# Other functionalities

Set

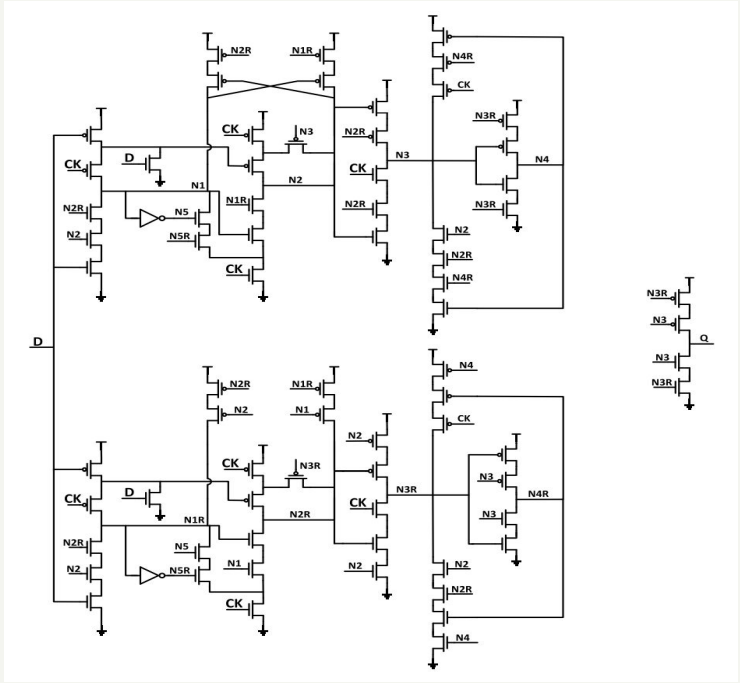



Reset



# Other functionalities

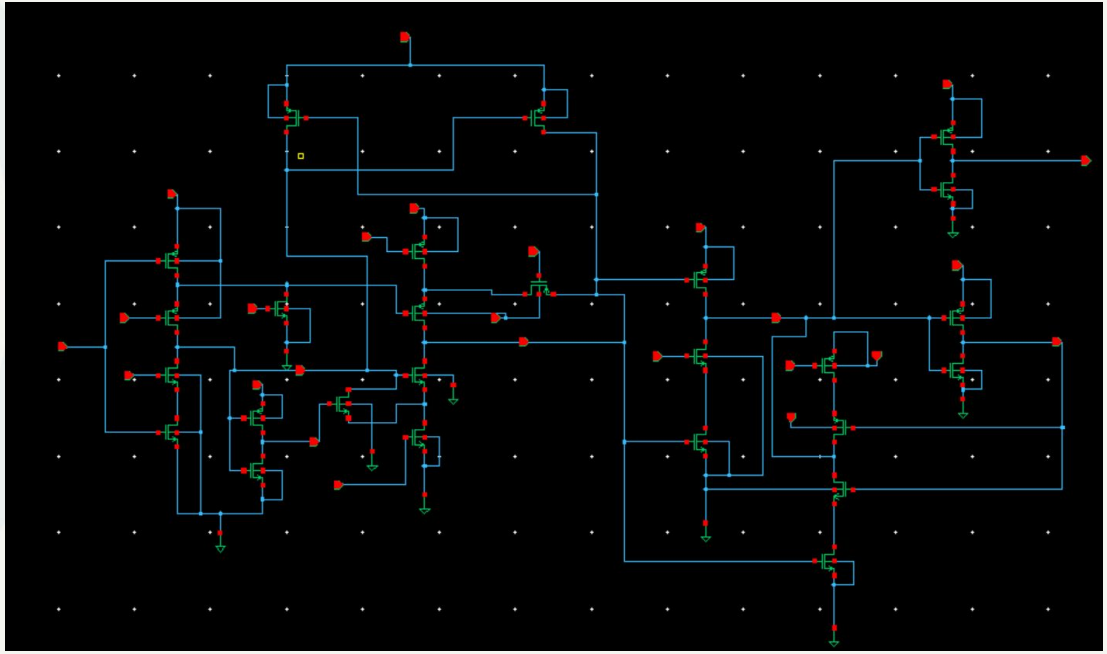
SEU tolerant design



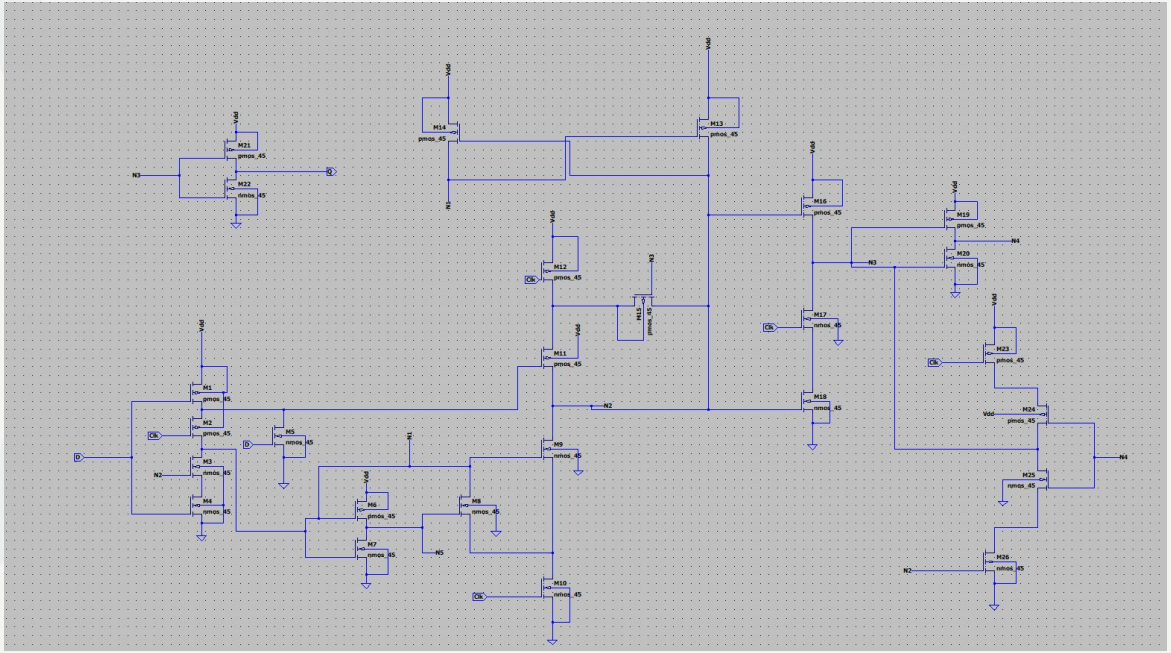
# IMPLEMENTATION

- Schematics
- Simulation results
- PSO

# PROPOSED-schematic



# PROPOSED-schematic



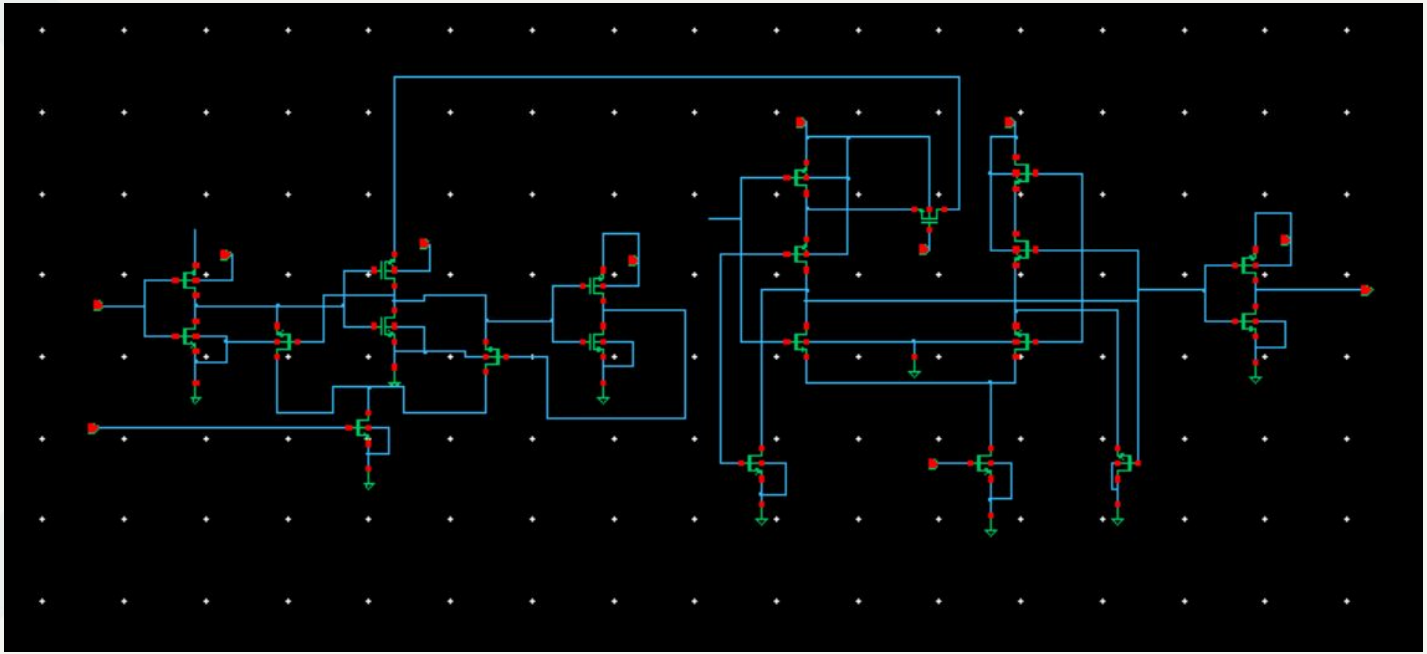
# PROPOSED -PSO

```
        LTC = SimCommander("proposed.asc")
        LTC.set_parameters(w1=W[i][0], w2=W[i][1], w3=W[i][2], w4=W[i][3], w5=W[i][4], w6=W[i][5], w7=W[i][6], w8=W[i][7], w9=W[i][8], w10=
        LTC.run()
        LTC.wait_completion()
        f = open("proposed_1.log", "r")
        data = f.read()
        x = data.split("\n")
        for j in range(len(x)):
            if x[j][0:6] == "delay:":
                print(x[j])
                pdp_str = x[j].split("=")
                pdp[i] = float(pdp_str[1])
                break
    return pdp
```

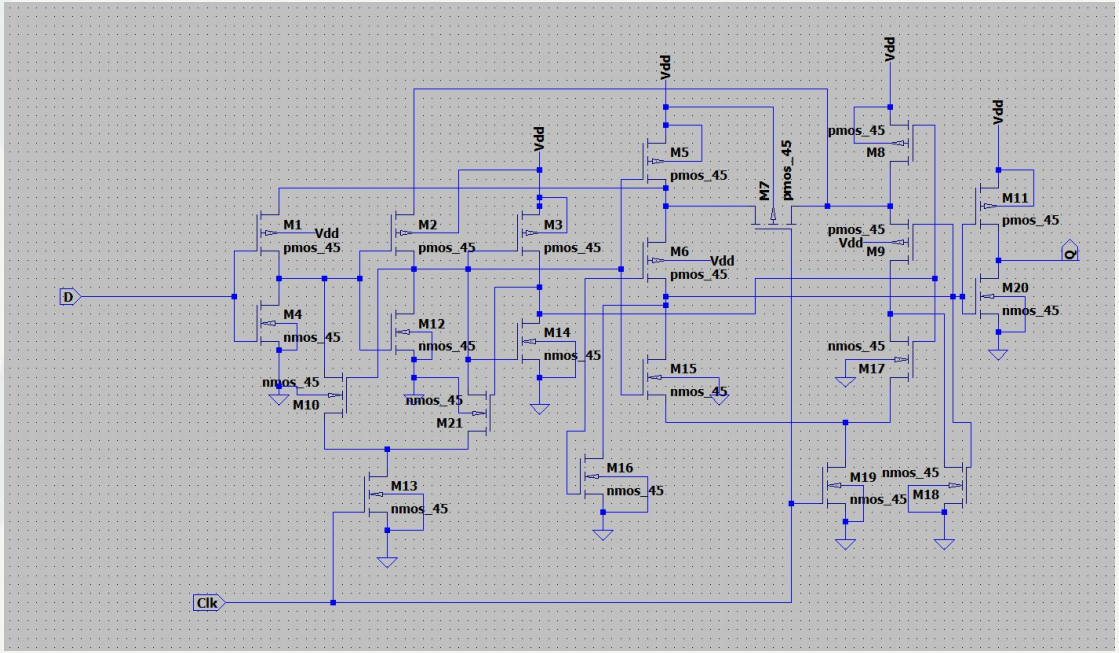
PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL powershell

```
Wed Apr 19 19:25:14 2023: Simulation Successful. Time elapsed 00:00:00:

No Callback
delay: t2-t1=5.01254e-008
pyswarms.single.global_best: 100%|                                                                                |15/15, best_cost=2.19e-11
2023-04-19 19:25:15,098 - pyswarms.single.global_best - INFO - Optimization finished | best cost: 2.18753e-11, best pos: [2.59074645e-07 9.59433679e-08 2.
09096585e-07 1.23764684e-07
 4.87313999e-07 7.79788916e-07 8.79828603e-07 8.79964274e-07
 8.55591165e-07 8.92113660e-07]
```

# TCFF - schematic



# TCFF - schematic



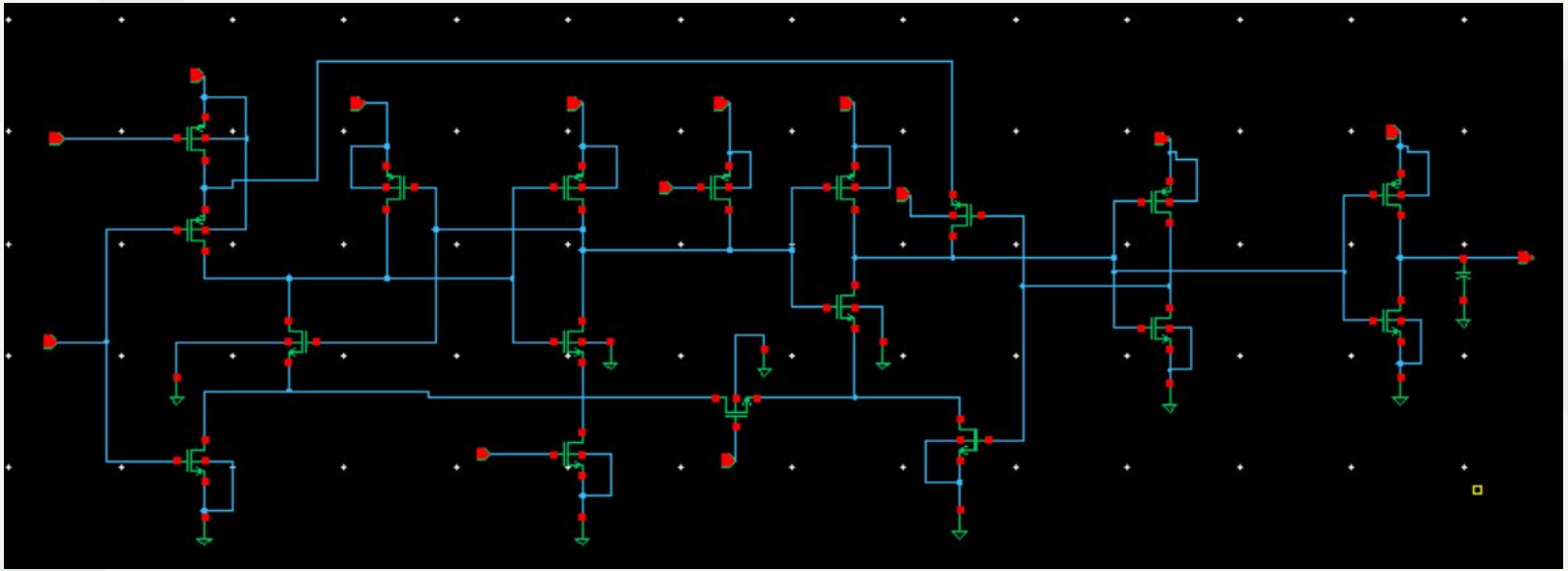
# TCFF -PSO

```
        f = open("TCFF_1.log", "r")
        data = f.read()
        x = data.split("\n")
        for j in range(len(x)):
            if x[j][0:6] == "delay:":
                print(x[j])
                pdp_str = x[j].split("=")
                pdp[i] = float(pdp_str[1])
                break
    return pdp


min_bound = np.ones(n)*90e-9
max_bound = np.ones(n)*900e-9
bounds = (min_bound, max_bound)
options = {'c1': 0.5, 'c2': 0.3, 'w':0.9}
optimizer = ps.single.GlobalBestPSO(n_particles=10, dimensions=n, options=options, bounds=bounds)
cost, pos = optimizer.optimize(LTSpice_PSO, iters=15)
```

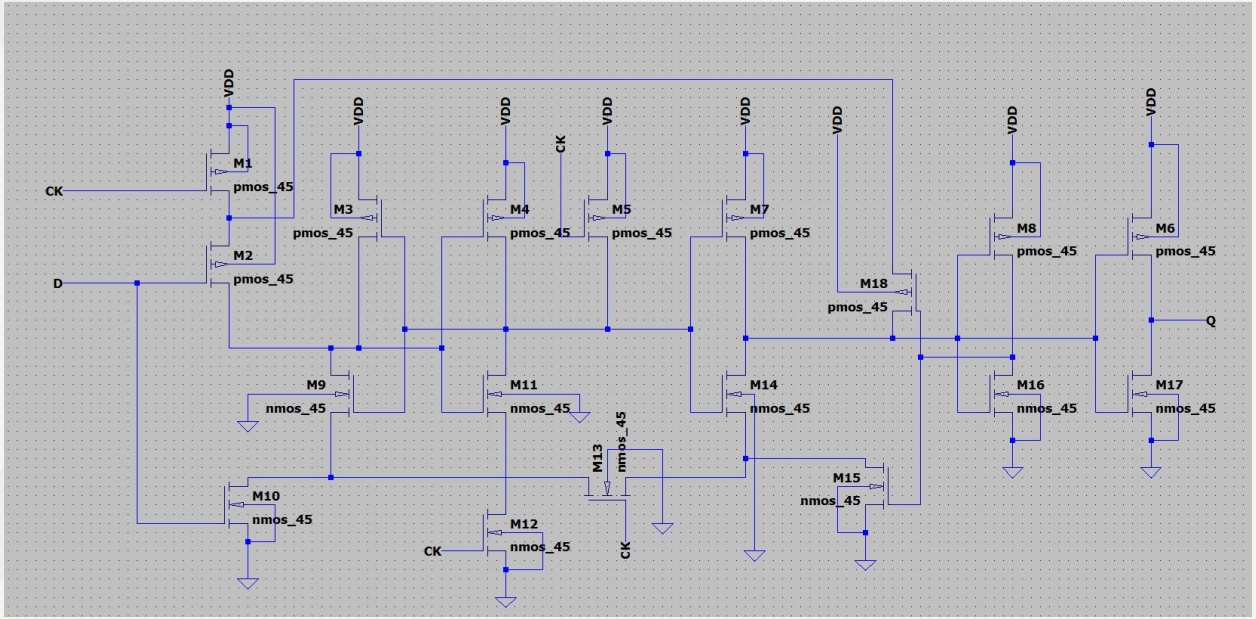
PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL powershell

```
Wed Apr 19 18:58:10 2023: Simulation Successful. Time elapsed 00:00:00:

No Callback
delay: t2-t1=5.03732e-009
pyswarms.single.global_best: 100%|██████████|15/15, best_cost=2.47e-9
2023-04-19 18:58:10,964 - pyswarms.single.global_best - INFO - Optimization finished | best cost: 2.47456e-09, best pos: [1.44976566e-07 9.84708441e-08 3.
37603187e-07 5.33013722e-07
 9.10783126e-08 6.53944782e-07 7.69141045e-07 7.06704056e-07
 6.48584333e-07 4.92087067e-07 2.58110692e-07 2.02394602e-07]
```

# SPC-18T - schematic



# SPC-18T - schematic



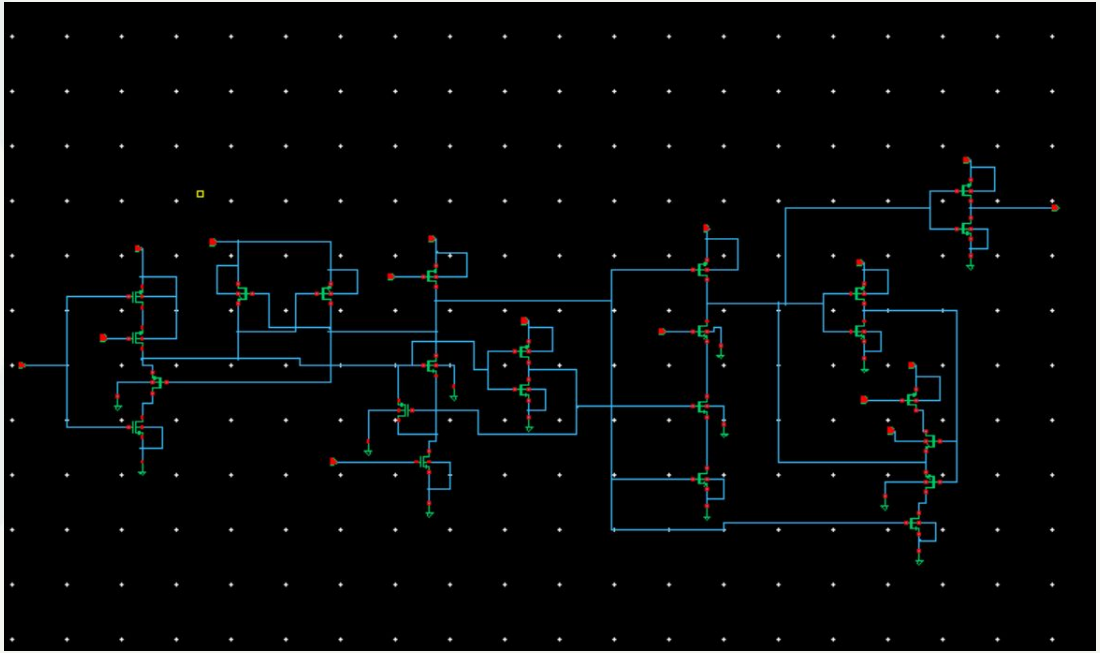
# SPC-18T-PSO

```
        LTC.wait_completion()
        f = open("SPC-18T_1.log", "r")
        data = f.read()
        x = data.split("\n")
        for j in range(len(x)):
            if x[j][0:6] == "delay:":
                print(x[j])
                pdp_str = x[j].split("=")
                pdp[i] = float(pdp_str[1])
                break
    return pdp


min_bound = np.ones(n)*90e-9
max_bound = np.ones(n)*900e-9
bounds = (min_bound, max_bound)
options = {'c1': 0.5, 'c2': 0.3, 'w':0.9}
```

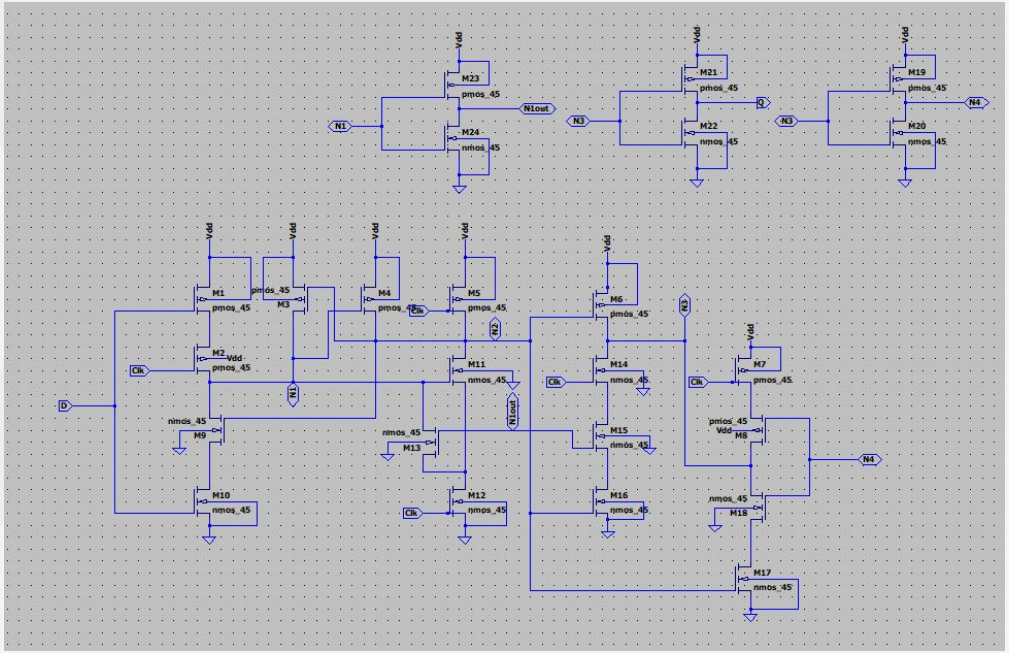
PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL powershell

```
Wed Apr 19 19:37:49 2023: Simulation Successful. Time elapsed 00:00:00:

No Callback
delay: t2-t1=6.78943e-011
pyswarms.single.global_best: 100%|██████████|15/15, best_cost=4.65e-11
2023-04-19 19:37:49,806 - pyswarms.single.global_best - INFO - Optimization finished | best cost: 4.65143e-11, best pos: [7.60614974e-07 5.17035478e-07 4.
29677752e-07 7.34851441e-07
 6.70678631e-07 4.01188724e-07 7.38188826e-07 7.69805332e-07
 1.56326045e-07]
```

# S2CFF - schematic



# S2CFF - schematic



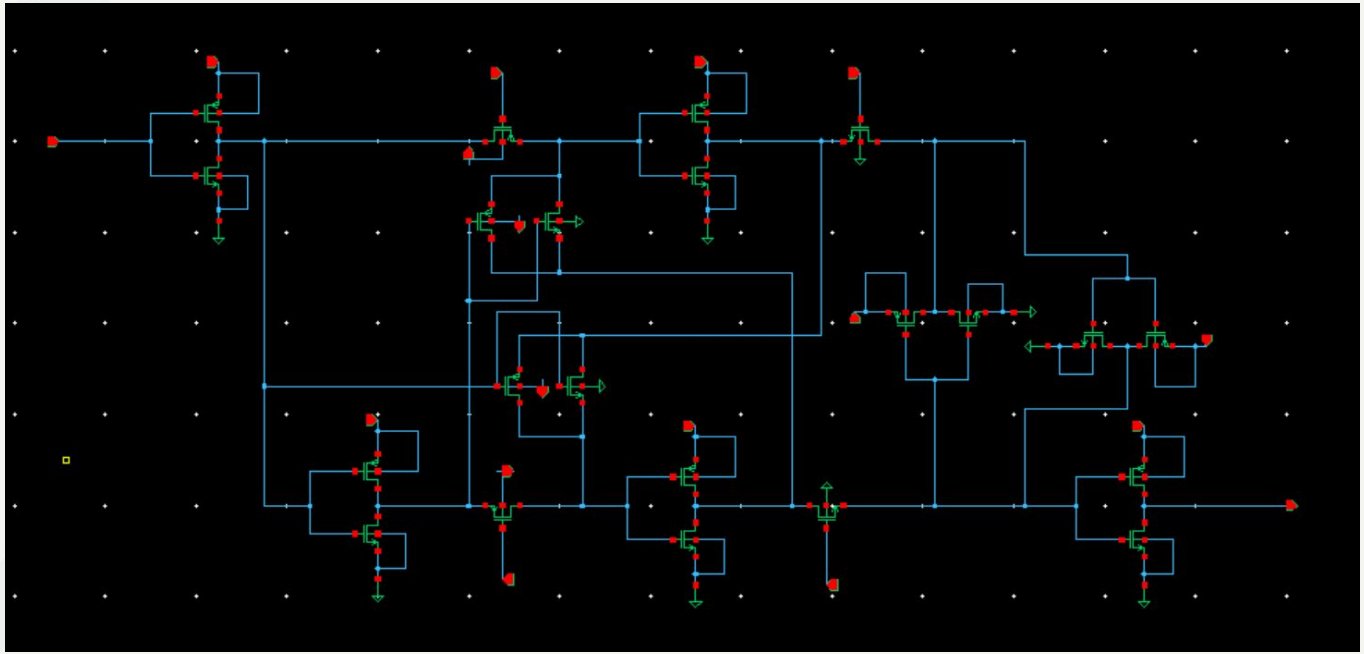
# S2CFF-PSO

```python
def LTSpice_PSO(W):
    pdp = [100.0]*10
    for i in range(10):
        LTC = SimCommander("s2cff.asc")
        LTC.set_parameters(w1=W[i][0], w2=W[i][1], w3=W[i][2], w4=W[i][3], w5=W[i][4], w6=W[i][5], w7=W[i]
        LTC.run()
        LTC.wait_completion()
        f = open("s2cff_1.log", "r")
        data = f.read()
        x = data.split("\n")
        for j in range(len(x)):
            if x[j][0:6] == "variable:":
                print(x[j])
                pdp_str = x[j].split("=")
                pdp[i] = float(pdp_str[1])
                break
```

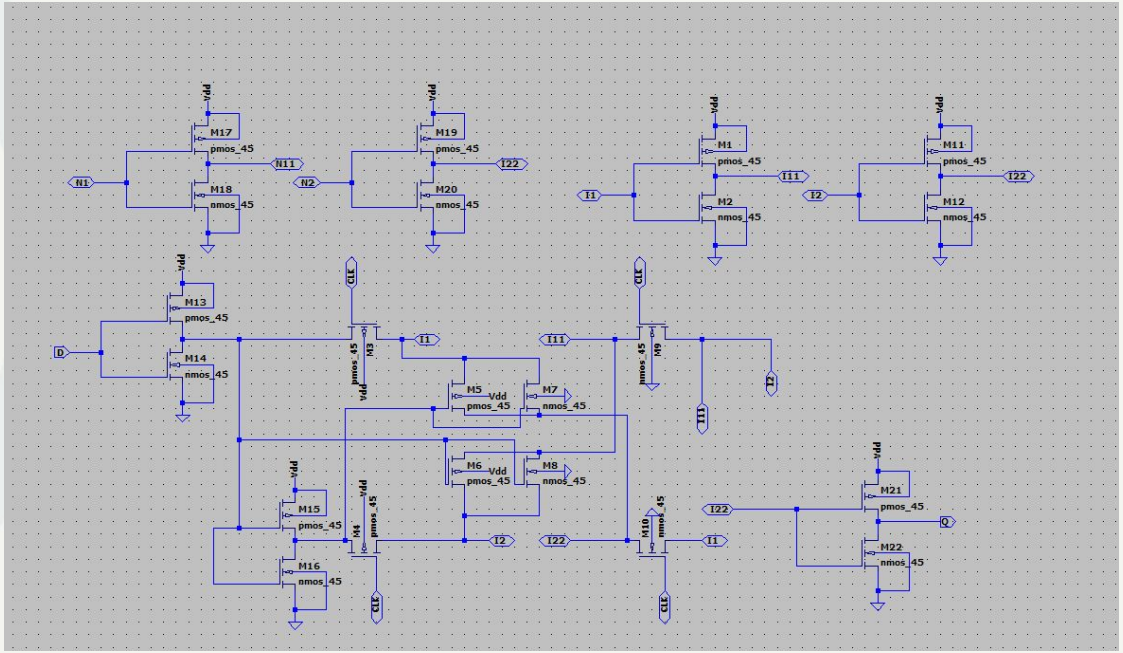
PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL powershell

```
Creating Netlist
The Netlist was successfully created
Sun Apr 16 20:18:33 2023 : Starting simulation 1
2023-04-16 20:18:34,668 - sim1 - INFO - Simulation Successful. Time elapsed: 00:00:00
Sun Apr 16 20:18:34 2023: Simulation Successful. Time elapsed 00:00:00:

No Callback
pyswarms.single.global_best: 100%|██████████|15/15, best_cost=100
2023-04-16 20:18:34,683 - pyswarms.single.global_best - INFO - Optimization finished | best cost: 100.0, best pos: [1.213
50582e-07 3.94788192e-07 8.89488906e-07 4.42240482e-07
 8.45720768e-07 1.26165749e-07 8.98917095e-07 7.21013243e-07
 5.19095423e-07 3.00992282e-07]
PS C:\Users\HP\Documents\pso_project>
```

# ACFF - schematic



# ACFF - schematic



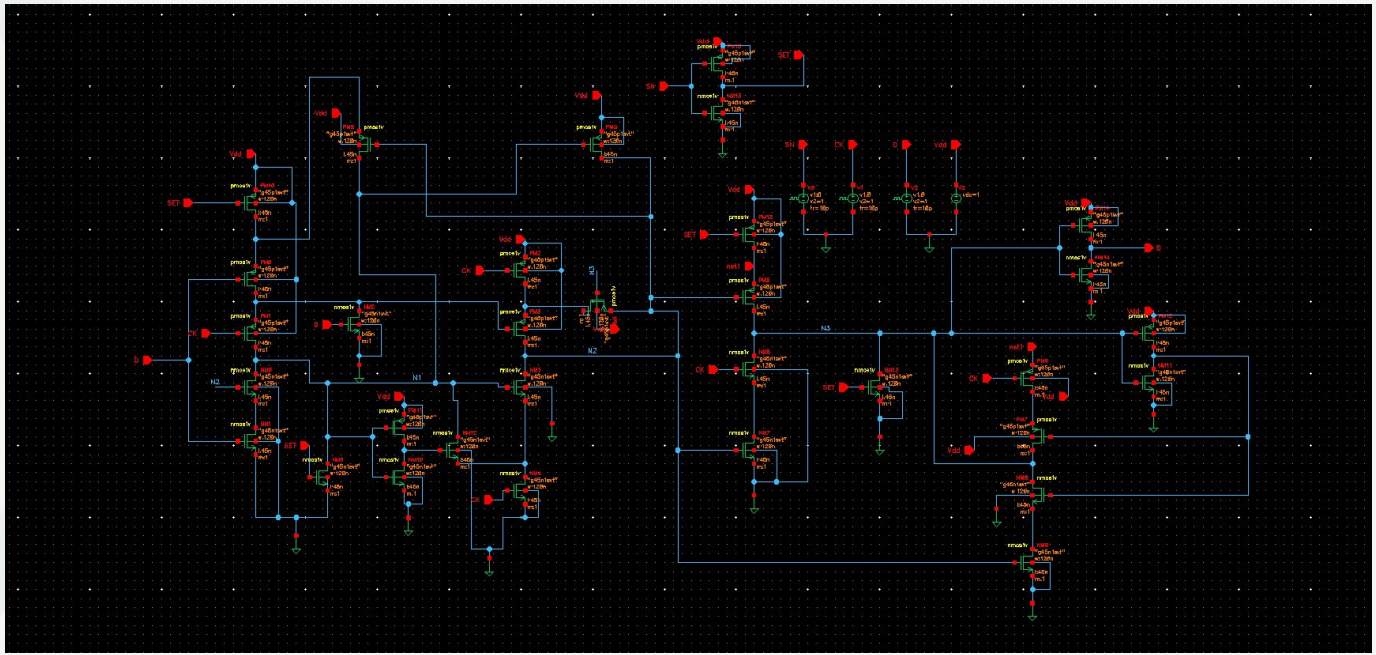
# ACFF-PSO

```
        LTC = SimCommander("ACFF.asc")
        LTC.set_parameters(w1=W[i][0], w2=W[i][1], w3=W[i][2], w4=W[i][3])#, w5=W[i][4], w6=W[i][5], w7=W[i][6], w8=W[i][7], w9=W[i][8], w1
        LTC.run()
        LTC.wait_completion()
        f = open("ACFF_1.log", "r")
        data = f.read()
        x = data.split("\n")
        for j in range(len(x)):
            if x[j][0:6] == "delay:":
                print(x[j])
                pdp_str = x[j].split("=")
                pdp[i] = float(pdp_str[1])
                break
    return pdp
```

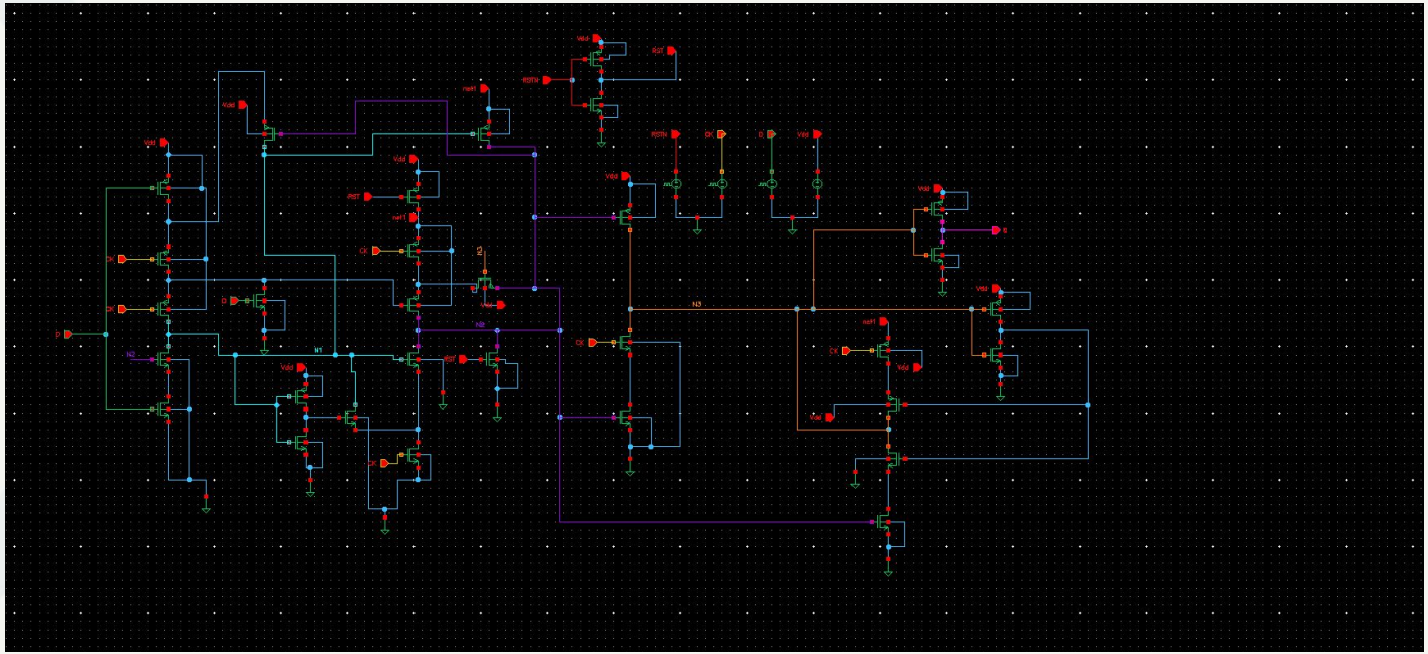
PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL powershell

```
Wed Apr 19 19:10:24 2023 : Starting simulation 1
2023-04-19 19:10:26,363 - sim1 - INFO - Simulation Successful. Time elapsed: 00:00:00
Wed Apr 19 19:10:26 2023: Simulation Successful. Time elapsed 00:00:00:

No Callback
delay: t2-t1=2.8985e-010
pyswarms.single.global_best: 100%|                                                                                |15/15, best_cost=1.95e-10
2023-04-19 19:10:26,400 - pyswarms.single.global_best - INFO - Optimization finished | best cost: 1.95011e-10, best pos: [1.72589986e-07 1.27837533e-07 3.
79985917e-07 1.64602865e-07]
```

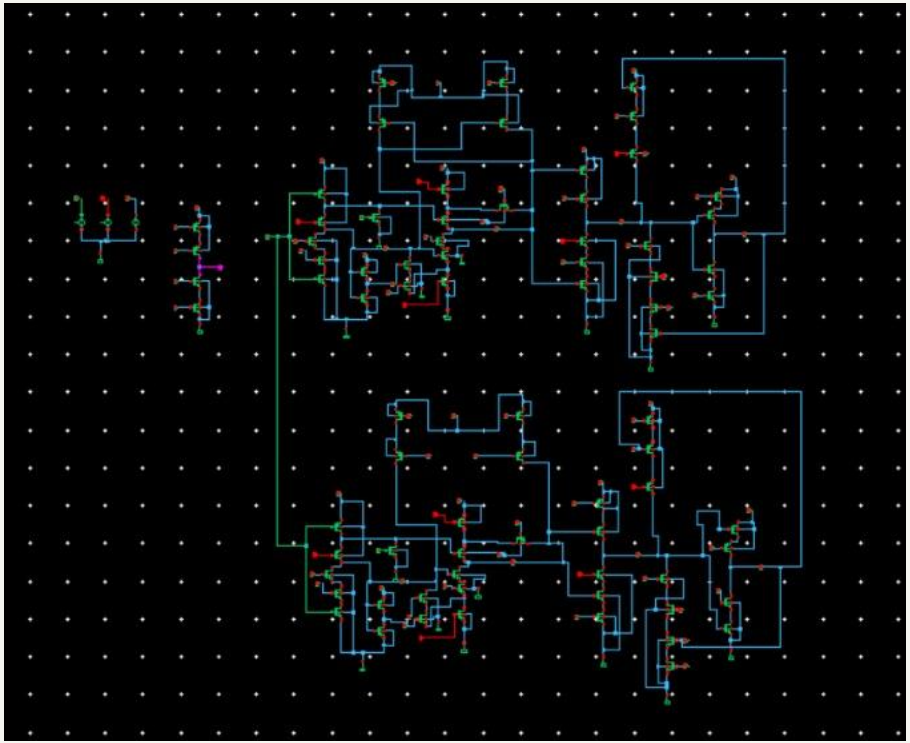
# SET - schematic



# RESET - schematic



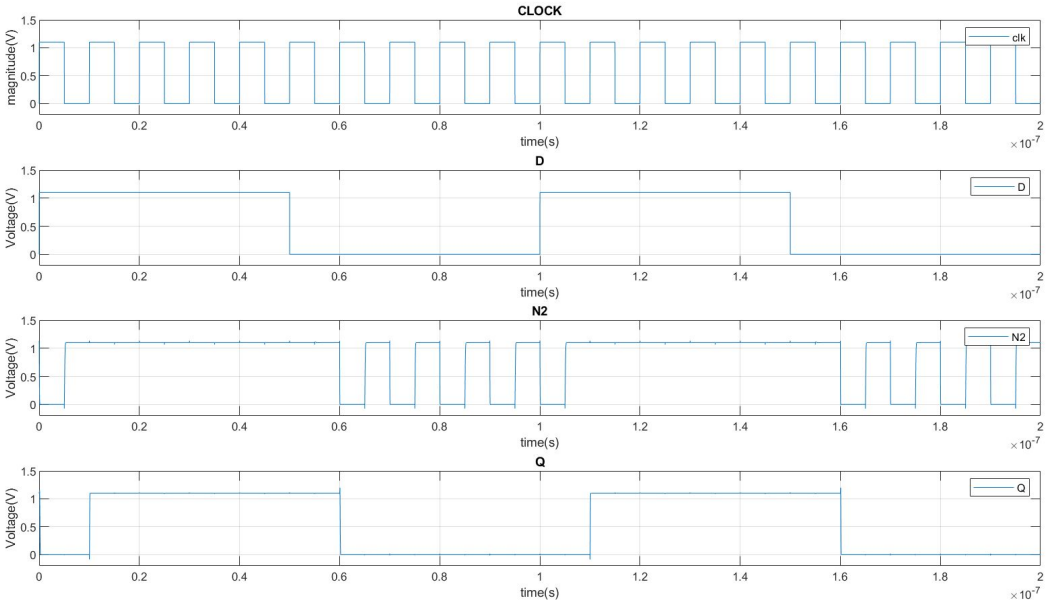
# SEU - schematic



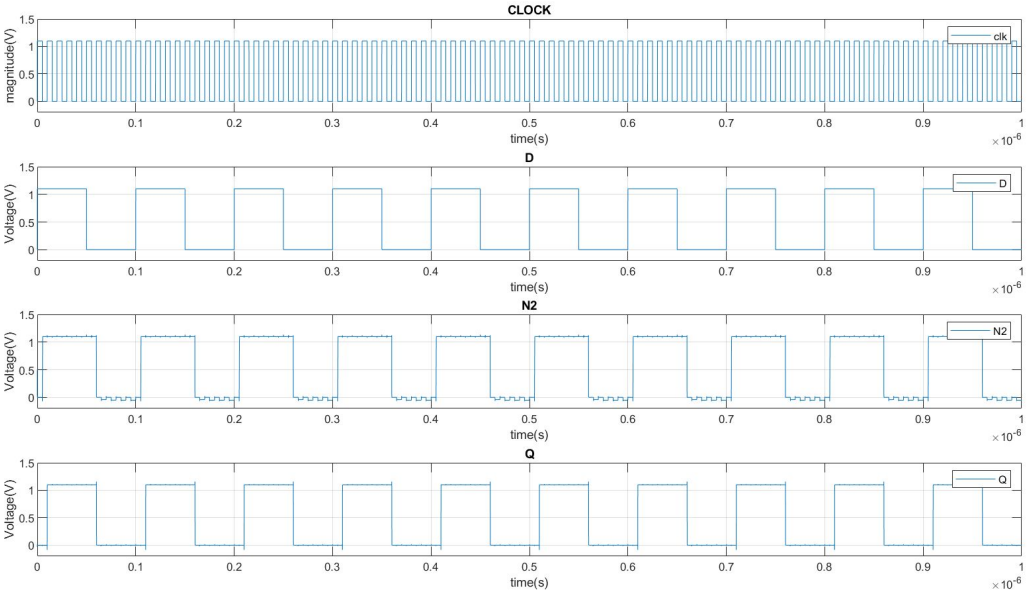
# Results

- Supply voltage vs Power
- Data activity vs Power
- Supply voltage vs Setup time
- Supply voltage vs Hold time

# Simulation of S2CFF



# Simulation of Proposed



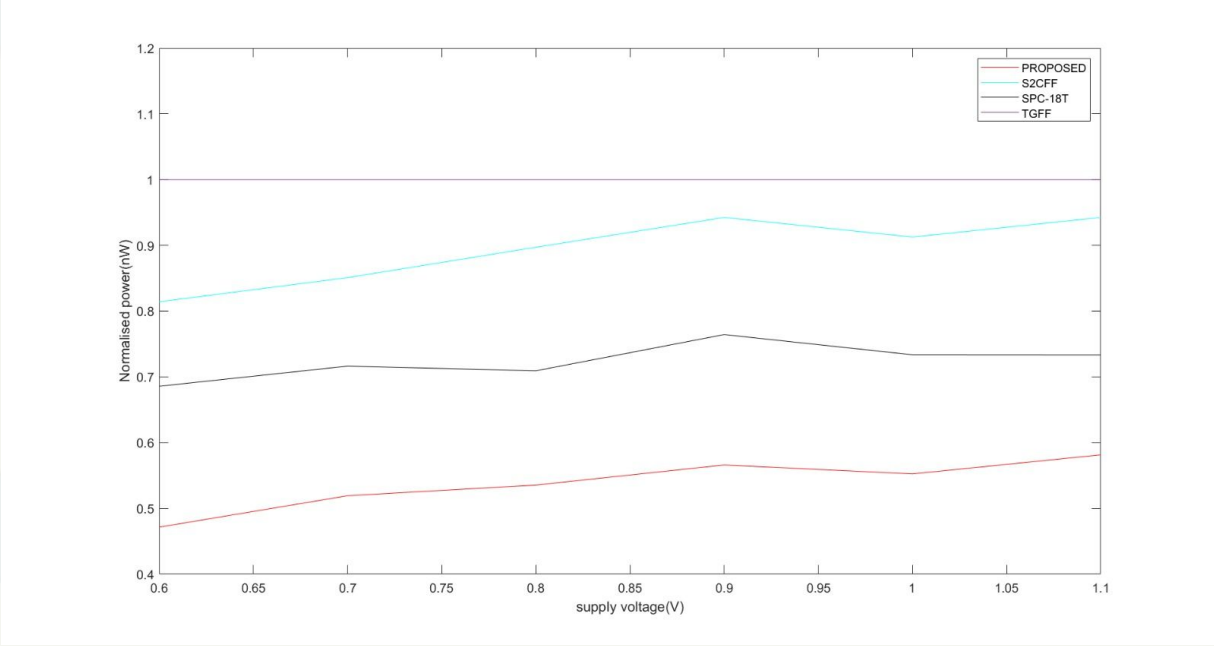
# Supply voltage vs Normalised Power

Power in nW

| Supply voltage (V) | SPC-18T | TGFF | Proposed | s2cff |
|---|---|---|---|---|
| 0.6 | 96 | 140 | 66 | 114 |
| 0.7 | 149 | 208 | 108 | 177 |
| 0.8 | 200 | 282 | 151 | 253 |
| 0.9 | 266 | 348 | 197 | 328 |
| 1 | 336 | 458 | 253 | 418 |
| 1.1 | 396 | 540 | 314 | 509 |

Data activity = 10% and clk at 100MHz

# Supply voltage vs Normalised Power



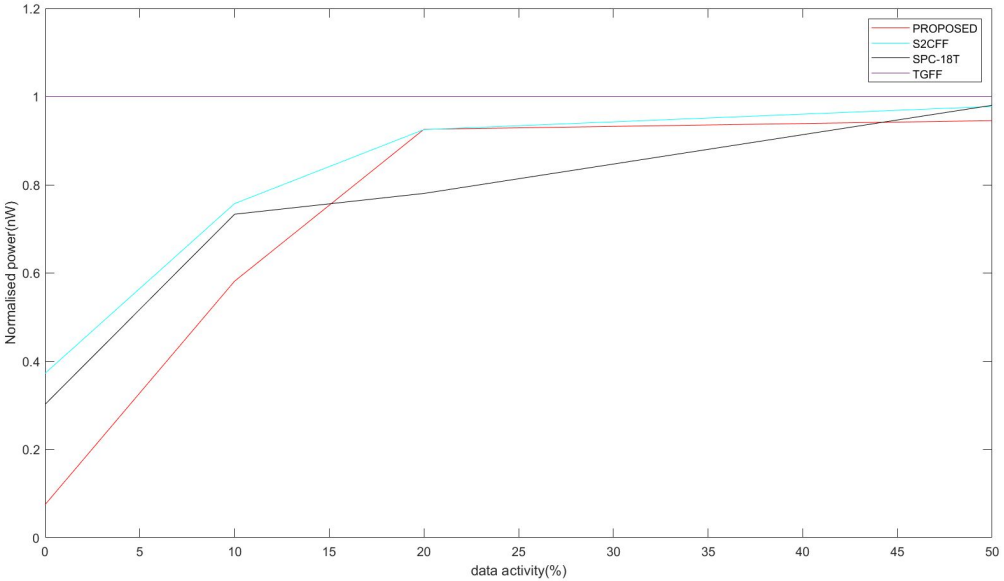
# Data activity vs Normalised Power

Power in nW

| Data activity (%) | SPC-18T | TGFF | Proposed | s2cff |
|---|---|---|---|---|
| 0 | 120 | 397 | 30 | 148 |
| 10 | 396 | 540 | 314 | 409 |
| 20 | 605 | 648 | 613 | 632 |
| 50 | 907 | 1162 | 1072 | 1078 |

Supply voltage = 1.1V
and clk at 100MHz

# Data activity vs Normalised Power

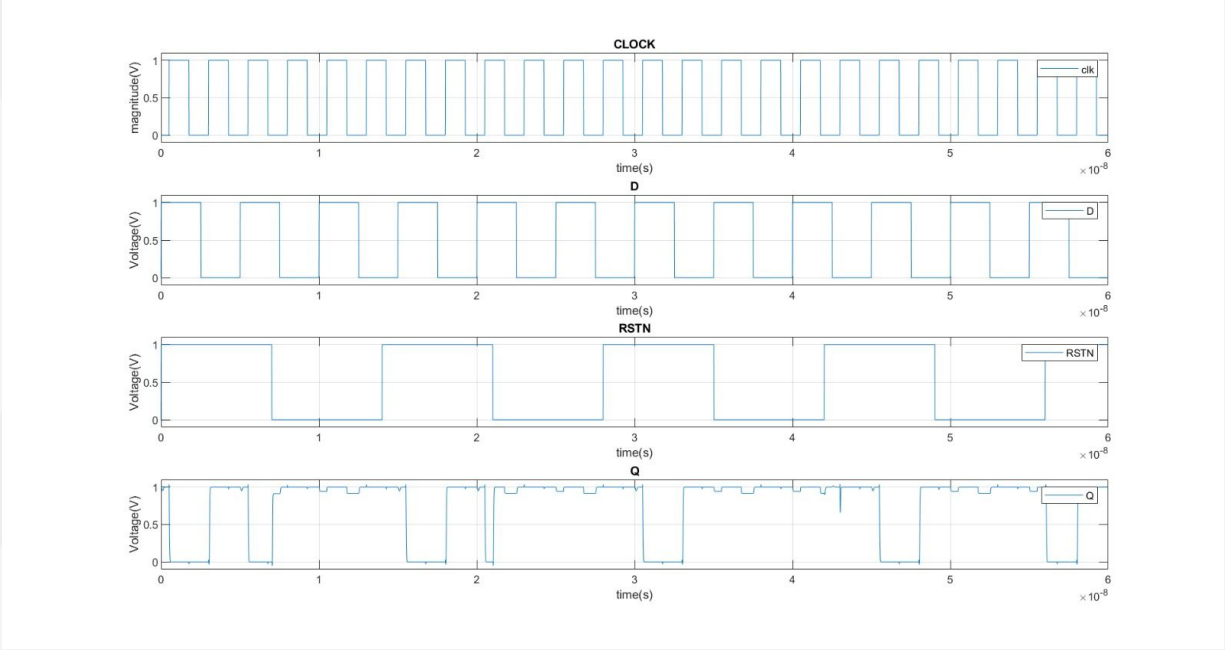


# Results

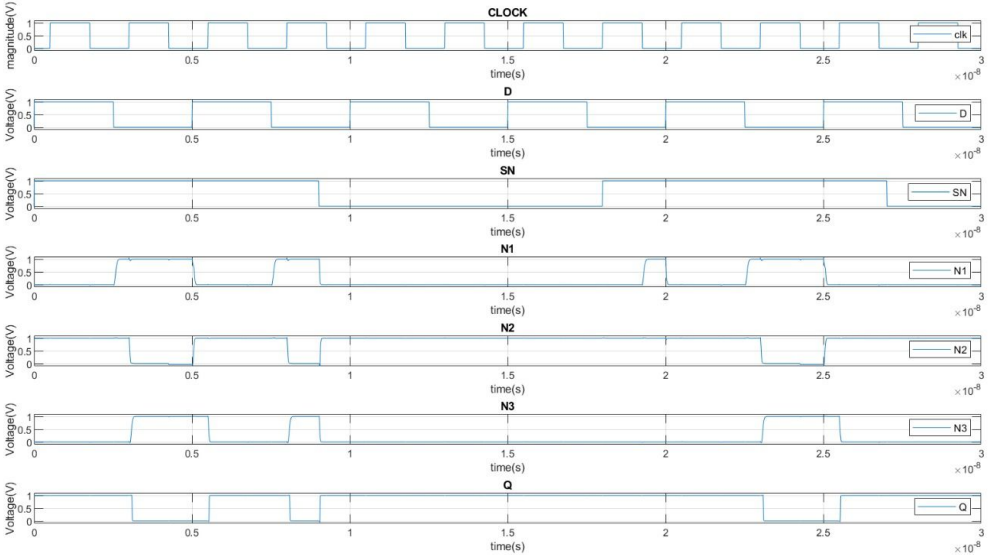
| Parameter | TGFF | SPC-18T | s2cff | Proposed |
|---|---|---|---|---|
| Clock to q (ps) | 118.2 | 48.5 | 49 | 32 |
| Power nW | 540 | 396 | 509 | 314 |
| PDP fJ | 0.06 | 0.019 | 0.02 | 0.01 |

Data activity = 10%
Clk at 100MHz
Supply Voltage = 1.1V

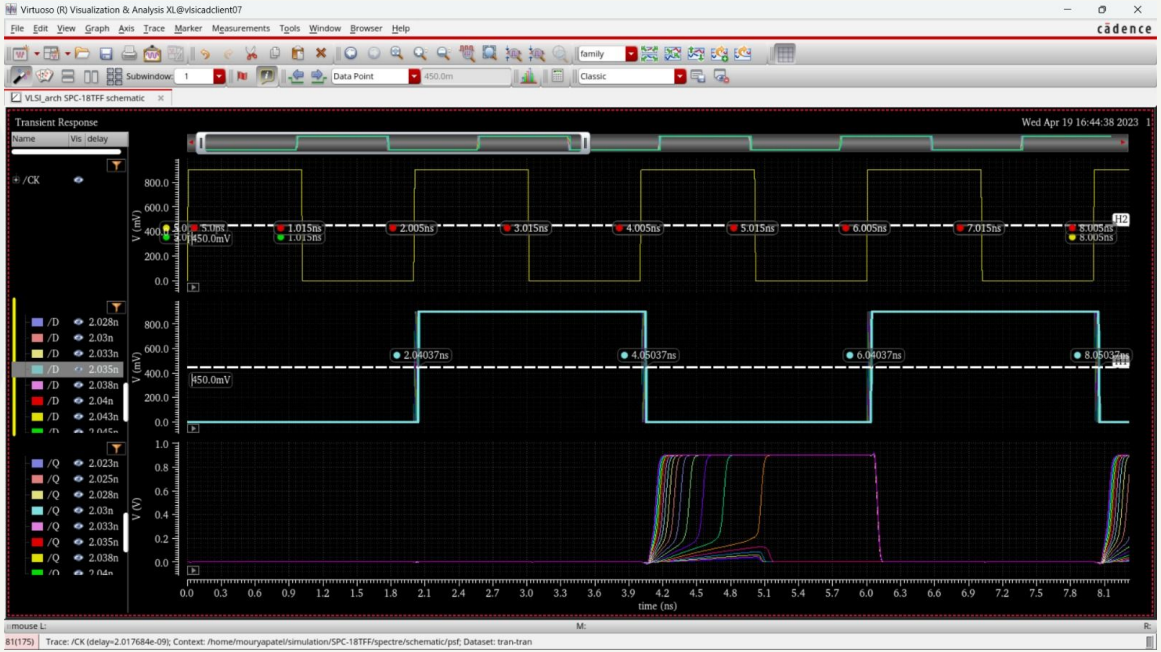
# Simulation of Proposed design with Reset



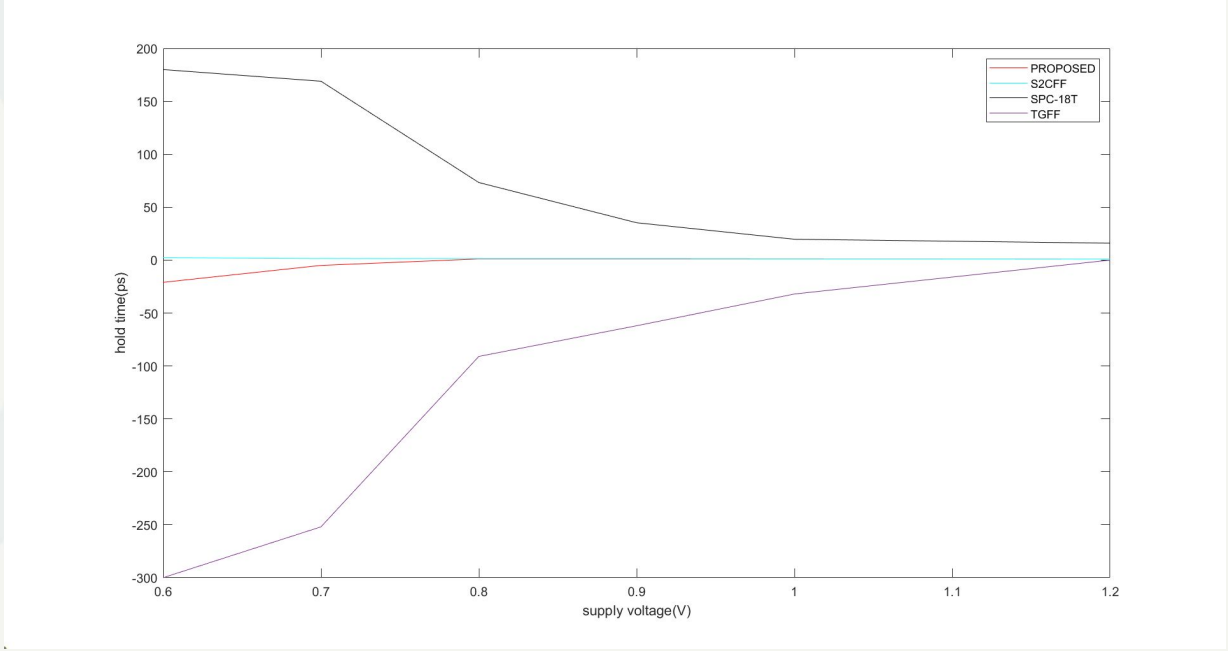
# Simulation of proposed design with set signal



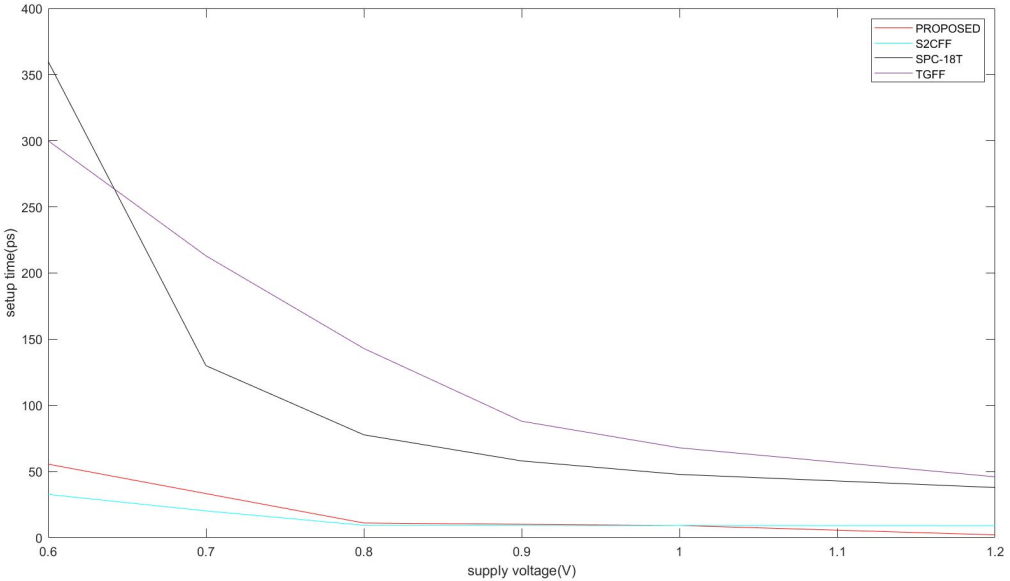
# Simulation for calculating setup and hold time



# Supply voltage vs Hold time



# Supply voltage vs Setup time



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